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Effect of Adjuvants and Urea Ammonium Nitrate on Bispyribac Efficacy, Absorption, and Translocation in Barnyardgrass (*Echinochloa crus-galli*). I. Efficacy, Rainfastness, and Soil Moisture

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Bispyribac is registered for postemergence control of broadleaf, sedge, and grass weeds in rice. Bispyribac inhibits the acetolactate synthase enzyme in sensitive plants. Herbicides in this class of chemistry require a spray adjuvant to achieve optimal efficacy, often achieve different levels of weed control according to the spray adjuvant used, and typically have rainfast periods of at least 6 to 8 h. Efficacy and rainfastness of bispyribac can be affected by spray adjuvant and the addition of urea ammonium nitrate (UAN). Greenhouse experiments were conducted to investigate the effect of spray adjuvant type, addition of UAN, and soil moisture on bispyribac efficacy on barnyardgrass. Control of barnyardgrass was improved when UAN was added to bispyribac at 0.4 or 0.8 g ha^{-1} plus an organosilicone-based nonionic surfactant (OSL/NIS) or methylated seed oil/organosilicone (MSO/OSL) spray adjuvant. The type of adjuvant added to the spray solution affected bispyribac efficacy on barnyardgrass. The addition of UAN decreased the rainfast period from 8 h (registered rainfast period) to 1 or 4 h (99 to 100% control) when either the OSL/NIS or MSO/OSL adjuvant was applied with bispyribac, respectively. Applying UAN and OSL/NIS or MSO/OSL adjuvant with bispyribac enhanced efficacy and reduced the time period required between bispyribac application and washoff during a rainfall event. Increasing soil moisture conditions resulted in greater efficacy from bispyribac when applied with and without UAN.
Nomenclature: Bispyribac; barnyardgrass, *Echinochloa crus-galli* (L.) Beauv. ECHCG; rice, *Oryza sativa* L.
Key words: ALS herbicide, herbicide washoff, UAN, weed control.

Bispyribac is a selective herbicide that has postemergence (POST) activity on grass, broadleaf, and sedge weed species common to rice production systems of the United States. Bispyribac provides preflood control of barnyardgrass and Amazon sprangletop [*Leptochloa panicoides* (J. Presl) A.S. Hitchc.] (Schmidt et al. 1999; Williams 1999). Bispyribac also controls several broadleaf weed species common to rice production systems, such as hemp sesbania [*Sesbania exaltata* (Raf.) Rydb. ex A. W. Hill] and northern jointvetch [*Aeschynomene virginica* (L.) B.S.P.] (Anonymous 2006; Williams 1999). Bispyribac is commonly applied in dry- and water-seeded rice before establishment of permanent flood when weeds are small and actively growing.

Bispyribac is a member of the pyrimidinyloxybenzoic chemical family (Vencill 2002) and inhibits the enzyme acetohydroxy acid synthase, also known as acetolactate synthase (ALS), in susceptible plants. Bispyribac inhibits the ALS enzyme in a similar fashion as the sulfonylurea and imidazolinone classes of herbicides (Vencill 2002). ALS is a critical enzyme in the biosynthesis pathway for the production of branched-chain amino acids valine, leucine, and isoleucine in plants (Shaner and Singh 1997; Tan et al. 2005). The sulfonylurea class of herbicides exhibit pre-emergence and POST activity on a broad spectrum of weed species, are effective at low application rates, have low mammalian toxicity profiles, and maintain a favorable environmental profile (Tan et al. 2005).

Most herbicides that inhibit the ALS pathway are readily absorbed through plant foliage and are uploaded into the phloem via the weak acid phloem-trapping mechanism because of the pH gradient between the acidic apoplastic cell wall area (pH 5.5 to 6.0) and the alkaline phloem sap (pH 8.0) (Beyer et al. 1988). However, with respect to herbicide efficacy, little literature exists on the effect of spray adjuvants as well as liquid nitrogen carriers on bispyribac efficacy in problematic weed species.

The effect of spray adjuvants such as surfactants and the addition of urea ammonium nitrate (UAN) to the spray solution on herbicide efficacy is well documented in the literature. The phytotoxicity of POST herbicides can be increased with the addition of spray adjuvants to spray solutions (Bunting et al. 2004; Harker 1992; Hart et al. 1992). Surfactants can be especially effective in improving the biological activity of sulfonylurea herbicides (Green and Cahill 2003; Green and Green 1993; Manthey et al. 1992). Specifically, the addition of a methylated seed oil (MSO) or organosilicone (OSL) adjuvant to spray solutions can enhance spray retention, foliar absorption of the herbicide, and subsequent herbicide efficacy (Bunting et al. 2004; Hart et al. 1992; Jordan 1996; Nalewaja et al. 1995). The addition of an OSL adjuvant to primisulfuron spray solution increased foliar herbicide absorption, spray retention, and control of giant foxtail (*Setaria faberi* Herrm.) compared with adding a nonionic surfactant (NIS) to the spray solution (Hart et al. 1992). The addition of UAN or ammonium sulfate to the spray solution can enhance herbicide effectiveness by further increasing herbicide absorption (Bunting et al. 2004; Miller et al. 1999). Bunting et al. (2004) reported 20% control of giant foxtail when a crop oil concentrate (COC) or a NIS was added to foramsulfuron, whereas control increased to 90 and 85%, when 28% UAN was added to COC or NIS, respectively. The importance of spray adjuvants to efficacy of many herbicides has been well researched. However, research on the effect of spray adjuvants on bispyribac efficacy is needed because limited literature regarding the potential for spray adjuvants to enhance bispyribac efficacy exists.

The potential activity of POST herbicides can be reduced by washoff from precipitation before complete absorption of the herbicide (Bryson 1987, 1988; Roggenbuck et al. 1990).

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Field and Bishop (1988) and Roggenbuck et al. (1990) reported that the addition of an OSL to glyphosate reduced its critical rain-free period. The reduction of the critical rain-free period was attributed to decreased liquid surface tension of glyphosate caused by the OSL and subsequent promotion of stomatal infiltration of glyphosate into the plant. Roggenbuck et al. (1990) attributed increased rainfastness and efficacy of several herbicides to the addition of an OSL to the herbicide spray solution. Decreasing the rainfast period with the addition of a spray adjuvant enhances herbicide utility and flexibility and decreases the risk of needing to reapply herbicide in the case of a rain event occurring within the rainfast period.

Environmental conditions such as soil moisture can affect herbicide efficacy by altering herbicide absorption, translocation, or metabolism (Hinz and Owen 1994; Levene and Owen 1995; Reynolds et al. 1988). Injury to downy brome (*Bromus tectorum* L.) and spring wheat (*Triticum aestivum* L.) was greater when soil moisture was at saturation compared with injury at one-third pot capacity (Olson et al. 2000). Control of blackgrass (*Alopecurus myosuroides* Huds.) with imazamethabenz increased with increasing soil moisture (Malefyt and Quakenbush 1991). Junglerice [*Echinochloa colona* (L.) Link] control by glyphosate was reduced with decreasing soil moisture conditions (Tanpipat et al. 1997). Bispyribac applied before permanent flood requires soil surface conditions suitable for operating ground equipment across treated fields. Thus, dry soil moisture conditions may prevail, subsequently affecting bispyribac efficacy. Identifying optimal bispyribac efficacy, as affected by interactions between the herbicide and spray adjuvant, under a range of soil moisture conditions will provide useful information to growers and applicators regarding the potential and flexibility for bispyribac use in rice production systems. A number of spray adjuvants are registered for use with bispyribac (Anonymous 2006).

No literature exists on the impact and interaction effects of spray adjuvant type, addition of UAN to the spray solution, or soil moisture content on bispyribac efficacy and rainfastness. Thus, the objectives of this research were to determine the effects of OSL type, addition of UAN, and soil moisture content on efficacy and rainfastness of bispyribac on barnyardgrass.

Materials and Methods

Seeds of barnyardgrass were purchased locally from a commercial vendor[1] and were stored at 4 C before use. Barnyardgrass seeds were planted in individual 11-cm-diam plastic pots containing a Bosket sandy loam (fine-loamy, mixed thermic Mollic Hapludalfs). Several plantings were conducted so that plants of different sizes could be treated simultaneously. Pots were subirrigated with deionized water for 3 d to initiate germination. After emergence, plants in each pot were thinned by hand to two plants per pot. Plants were subirrigated for 6 h once every 2 d with deionized water. Plants were not subirrigated for a 2-d period before treatment application. A 1% Hoagland's nutrient solution (Hoagland and Arnon 1950) was added to the water at every other irrigation timing. Pots were maintained in a greenhouse at 32/25 C (±3 C) day/night temperature. Natural light was supplemented with light from sodium vapor lamps to provide a 14-h photoperiod.

Bispyribac Efficacy. Barnyardgrass in the two- and five-leaf growth stage (20- and 30-cm tall, respectively) were treated with 0, 11.25, or 22.5 g ai ha^{-1} bispyribac plus 0 or 2% (v/v) of a 32% UAN liquid solution. An OSL-based NIS (OSL/NIS[2]) was added to all treatments at 0.25% (v/v) as suggested by the manufacturer. Treatments were applied with the use of an air-pressurized indoor spray chamber equipped with an 8002E flat fan nozzle[3] calibrated to deliver a spray volume of 190 L ha^{-1} at 140 kPa. After spraying, plants were returned immediately to the greenhouse and were subirrigated 1 d after treatment (DAT) and again every 2 d throughout the remainder of the experiment.

Initial herbicide efficacy on the basis of leaf discoloration and plant stunting was visually estimated for each plant at 4 DAT on a scale of 0% (no injury) to 100% (death) (Frans et al. 1986). Overall herbicide efficacy was estimated at 14 DAT by clipping shoots at the soil surface and recording plant fresh weight. Data were expressed as percent shoot biomass reduction (% control) compared with the aboveground portion of nontreated plants. Data were averaged for the two plants per pot. The experiment was conducted in a randomized complete block design with a factorial arrangement of treatments. Factors were plant growth stage, bispyribac rate, and addition of UAN. Treatments were replicated four times, and the experiment was repeated.

Effect of Adjuvant Type and UAN. An experiment with factorial arrangement of treatments was conducted. Factors included adjuvant type and addition of UAN to spray solution. Barnyardgrass in the five-leaf growth stage (30-cm tall) was treated with 22.5 g ha^{-1} bispyribac plus a component of factor 1 and a component of factor 2 (0 or 2% v/v UAN). Factor 1 included no adjuvant, OSL/NIS[2] at 0.25% (v/v), and a MSO/OSL[4] adjuvant applied at 0.4% (v/v) as suggested by the manufacturer. A nontreated control was included. Treatments were applied with the air-pressurized indoor spray chamber, and plants were returned immediately to the greenhouse and subirrigated as described previously in the bispyribac efficacy experiment.

Treatment efficacy was assessed by estimating reduction in plant height and aboveground biomass. Plant height at 6 DAT was estimated by measuring the distance between soil level and the tip of the youngest leaf extended vertically. Height reduction was expressed as percent reduction compared with the height of nontreated control. Aboveground biomass was clipped at the soil surface, and fresh weight was recorded at 14 DAT. Fresh weight data were expressed as percent shoot biomass reduction (% control) compared with aboveground portion of nontreated plants. Height and fresh weight data were averaged for the two plants per pot. The experiment was conducted in a randomized complete block design with treatments replicated four times, and the experiment was repeated.

Effect of Rainfall Timing. An experiment with a factorial arrangement of treatments was conducted. Factors included herbicide treatment, addition of UAN, and rainfall timing after herbicide treatment. Herbicide treatments included (1) no herbicide, (2) bispyribac at 22.5 g ha^{-1}, (3) bispyribac at

22.5 g ha^{-1} applied with OSL/NIS[2] at 0.25% (v/v), and (4) bispyribac at 22.5 g ha^{-1} applied with MSO/OSL[4] at 0.4% (v/v). Treatments 3 and 4 were applied with and without 2% (v/v) UAN to examine the effect of UAN on bispyribac efficacy. Treatments were applied with the air-pressurized indoor spray chamber, and plants were returned immediately to the greenhouse as described previously.

A 2.5-cm rainfall event (7.5 cm h^{-1} intensity) was applied with an indoor rainfall simulator to plants at 0.25, 0.5, 1, 4, 12, and 24 h after application of bispyribac treatments. The rainfall simulator was set to deliver droplets at a height of 2 m above plants, and the amount of delivered rainfall was measured at plant level with rainfall gauges. Plants were returned to the greenhouse immediately after rainfall simulation. A no-rainfall timing for each herbicide treatment was included.

Treatment efficacy was assessed by estimating plant fresh weight reduction at 14 DAT. Aboveground biomass was clipped at the soil surface, and fresh weight was recorded at 14 DAT. Fresh weight data were expressed as percent shoot biomass reduction (% control) compared with aboveground portion of nontreated plants. Nonlinear regression analysis was used to determine the effect of rainfall timing, adjuvant type, and addition of UAN to adjuvant on control of barnyardgrass. A sigmoidal log-logistic model was used to relate fresh weight reduction as a percent of the nontreated check (Y) to rainfall timing after bispyribac application (x):

$$Y = \frac{a}{1 + e^{-(x - X_0)/b}} \qquad [1]$$

In this equation, a is the difference of the upper and lower response limits (asymptotes), X_0 is the rainfall timing after bispyribac application that results in a 50% reduction in fresh weight, and b is the slope of the curve around X_0. Pseudo R^2 values were calculated to assess the goodness of fit for individual regression equations. R^2 values were obtained by subtracting the ratio of the residual sum of squares to the corrected total sum of squares from 1.0. The residual sum of squares was attributed to that variation not explained by the fitted line. The R^2 and residual mean squares were used to determine the goodness of fit to regression models. To evaluate overall effects of adjuvant treatment (with and without UAN) and rainfall timing after bispyribac application, means for adjuvant treatments when averaged across rainfall timings and for rainfall timings when averaged across adjuvant treatments were tested by ANOVA at the $P = 0.05$ level of significance. The experiment was conducted in a randomized complete block design with treatments replicated four times, and the experiment was repeated.

Soil Moisture Content. An experiment with treatments arranged in a factorial design was conducted. Factors included soil moisture content (SMC) and herbicide treatment. SMC treatments included (1) dry (approximately 11% SMC), (2) subirrigated as described previously (approximately 29% SMC), (3) subirrigated continuously for a 4-d period before herbicide application (approximately 40% SMC), and (4) flood irrigated up to soil level for 4 d before herbicide application (approximately 49% SMC). Irrigation was removed for plants of SMC treatments 3 and 4 just before herbicide application. Pots containing plants for SMC treatment 4 were submerged inside clear plastic buckets and flooded up to soil level. Deionized water was added to buckets as needed. Pots with no plants were included for each SMC treatment so that percent soil moisture could be determined gravimetrically (wt/wt) according to procedures described by Gardner (1986). Degree of transpiration by plants during the course of the research was not estimated because the measurement would have resulted in plant destruction. Thus, only qualitative soil moisture estimates were recorded according to the Gardner (1986) method.

Herbicide treatments included (1) no herbicide, (2) bispyribac at 22.5 g ha^{-1} plus OSL/NIS[2] at 0.25% (v/v), or (3) bispyribac at 22.5 g ha^{-1} plus OSL/NIS[2] at 0.25% (v/v) plus 2% (v/v) UAN. Treatments were applied with the air-pressurized indoor spray chamber, and plants were returned immediately to the greenhouse as described previously.

Treatment efficacy was assessed by estimating plant fresh weight reduction at 14 DAT. Aboveground biomass was clipped at the soil surface, and fresh weight was recorded at 14 DAT. Fresh weight data were expressed as percent shoot biomass reduction (% control) compared with aboveground portion of plants not treated with herbicide. The experiment was conducted in a randomized complete block design with treatments replicated four times, and the experiment was repeated.

Statistical Analysis. Data represent the mean of the two experiments because of no experiment by treatment interaction. Data were tested for homogeneity of variance by plotting residuals. An arcsine square root transformation was performed before analysis but did not improve variance homogeneity. Thus, nontransformed data were used in analysis and presentation. Variances were partitioned into the random effects of the experiment, replication within experiment, and interactions between random and fixed effects (herbicide, adjuvant, UAN, rainfall simulation timing, and soil moisture content treatments). Replication within each experiment was considered as a random variable within each experiment. Mean squares were tested appropriately on the basis of treatment design (McIntosh 1983). Data were subjected to ANOVA by the mixed model procedure in SAS (SAS 2001). Means were separated by Fisher's protected least significance difference (LSD) test at the 5% level of probability.

Results and Discussion

Bispyribac Efficacy. Interactions involving growth stage, bispyribac rate, and addition of UAN factors were not significant; however, the main effect of all factors was significant. Data are presented for each growth stage by bispyribac rate by addition of UAN combination to reveal treatment effect across all factors. Addition of UAN to bispyribac at 11.25 or 22.5 g ha^{-1} increased visual injury to two- and five-leaf barnyardgrass by 4 DAT when compared with bispyribac without UAN (Table 1). Injury was greater with bispyribac at 22.5 g ha^{-1} applied with or without UAN compared with the respective 11.25 g ha^{-1} with or without UAN treatment. UAN alone had no activity on barnyardgrass.

Biomass reduction (control) of two- and five-leaf barnyardgrass increased with the addition of UAN to bispyribac at 11.25 g ha^{-1} compared with bispyribac alone (Table 1). The higher rate of 22.5 g ha^{-1} offset any advantage of adding UAN with respect to biomass reduction because bispyribac at 22.5 g ha^{-1} applied with or without UAN controlled two- and five-leaf barnyardgrass 98 to 99%. Bispyribac at

Table 1. Effect of bispyribac rate and addition of urea ammonium nitrate (UAN) to spray solution on visual injury (4 d after treatment [DAT]) and biomass reduction (14 DAT) to two- and five-leaf barnyardgrass (ECHCG) in the greenhouse.[a]

Bispyribac rate[b]	UAN rate	Visual injury[c]		Biomass reduction[c,d]	
		Two-leaf	Five-leaf	Two-leaf	Five-leaf
g ai ha^{-1}	% (v/v)	%[d]			
11.25	0	26 c	15 c	86 b	84 b
11.25	2	36 b	28 b	96 a	96 a
22.5	0	39 b	26 b	99 a	99 a
22.5	2	47 a	36 a	99 a	98 a
0	2	0 d	0 d	−5 c	−2 c

[a] A 32% urea ammonium nitrate liquid solution was used in treatments.
[b] The spray adjuvant Kinetic HV[2] was added to each bispyribac treatment at 0.25% (v/v) as suggested by the manufacturer. Kinetic HV (OSL/NIS) is a 99% proprietary blend of polyalkyleneoxide-modified polydimethylsiloxane and polyoxypropylene–polyoxyethylene copolymers. Treatments were applied at a spray volume of 190 L ha^{-1} and 140 kPa pressure.
[c] Means followed by same letter within a column are not significantly different at $P \leq 0.05$.
[d] Reduction is expressed as percent fresh weight reduction compared with aboveground portion of nontreated plants (two-leaf and five-leaf nontreated plants weighed 5.8 and 8.1 g, respectively, at 14 DAT).

22.5 g ha^{-1} is the suggested 1× rate and is the lowest registered rate that should be applied to control barnyardgrass in the field (Anonymous 2006). The 1× rates of herbicides applied to plants in the greenhouse result in higher levels of control compared with applications to plants growing in the field (Koger et al. 2004, 2005). Thus, the 11.25 g ha^{-1} bispyribac rate applied in the greenhouse provides insight on the potential benefit of adding UAN for enhancing bispyribac efficacy on barynardgrass of various sizes.

Effect of Adjuvant Type and UAN. Addition of spray adjuvant was necessary for bispyribac efficacy on barnyardgrass because bispyribac applied alone without spray adjuvant provided no control (Table 2). Height and biomass reduction of barnyardgrass was greater when OSL/NIS was added as a spray adjuvant to bispyribac compared with MSO/OSL plus bispyribac. The addition of UAN to bispyribac plus either OSL/NIS or MSO/OSL increased height and biomass reduction when compared with bispyribac plus OSL/NIS or MSO/OSL applied without UAN. Bispyribac plus OSL/NIS and UAN provided the greatest height and biomass reduction.

Applying bispyribac with OSL/NIS in the absence of UAN provided similar levels of control as bispyribac plus MSO/OSL and UAN. The addition of UAN enhanced bispyribac efficacy when applied with either spray adjuvant. Efficacy was optimized by adding OSL/NIS and UAN to bispyribac. The addition of UAN to bispyribac spray solution is a viable option for enhancing bispyribac efficacy on troublesome grass species such as barnyardgrass in rice.

Effect of Rainfall Timing. Bispyribac applied without nonionic spray adjuvant and UAN controlled barnyardgrass 0 to 34% depending on rainfall timing (data not shown). Data for treatment of bispyribac applied without nonionic spray adjuvant and UAN was excluded from analysis because of label (Anonymous 2006) recommendations of not applying bispyribac in the absence of a recommended spray adjuvant.

Rainfall after herbicide application affected bispyribac efficacy on barnyardgrass (Figure 1). Biomass reduction of barnyardgrass increased in a sigmoidal fashion, with increasing time between bispyribac application (applied with or without nonionic spray adjuvant and UAN) and a rainfall event. Fresh weight reduction of barnyardgrass reached a peak plateau for each treatment and did not change when rainfall was applied more than 4 h after bispyribac application. Fresh weight reduction data for the rainfall timing of 24 h after bispyribac application was not included in regression analysis to allow for better visual presentation (Figure 1) of effect of rainfall between 0.25 and 4 h after bispyribac application.

Table 2. Effect of adjuvant type and addition of urea ammonium nitrate (UAN) to bispyribac applied at 22.5 g ai ha^{-1} on barnyardgrass, height reduction at 6 d after treatment (DAT), and biomass reduction at 14 DAT in the greenhouse.[a,b]

Adjuvant				
Type	Rate	UAN rate[c]	Height reduction[d]	Biomass reduction[e]
	% (v/v)	% (v/v)	%[f]	
No adjuvant	0	2	−5 d	−2 d
OSL/NIS[g]	0.25	0	48 b	62 b
OSL/NIS[g]	0.25	2	54 a	72 a
MSO/OSL[h]	0.25	0	41 c	55 c
MSO/OSL[h]	0.25	2	46 b	68 b

[a] Bispyribac was applied at 22.5 g ai ha^{-1} in all treatments at a spray volume of 190 L ha^{-1} and 140 kPa pressure.
[b] Barnyardgrass plants were in the five-leaf growth stage at time of bispyribac application.
[c] Organosilicone-based nonionic adjuvant[2] that is a proprietary blend of polyalkyleneoxide-modified polydimethylsiloxane and polyoxypropylene–polyoxyethylene copolymers.
[d] Methylated seed oil/organosilicone–based nonionic emulsifier adjuvant[4] that is a proprietary blend of polyalkyleneoxide–modified polydimethylsiloxane, nonionic emulsifiers, and methyl esters of C16–C18 fatty acids.
[e] A 32% urea ammonium nitrate liquid solution was used in treatments.
[f] Expressed as percent reduction in height compared with height of nontreated plants (nontreated plants were 46 and 62 cm tall, respectively, at 6 DAT).
[g] Expressed as percent fresh weight reduction compared with aboveground portion of nontreated plants, which weighed 16.4 g at 14 DAT.
[h] Means followed by the same letter within a column are not significantly different at $P \leq 0.05$.

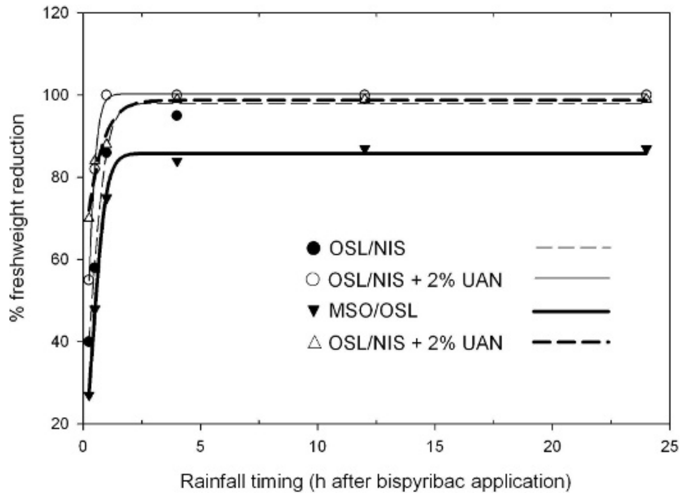

Figure 1. Effects of adjuvant type, urea ammonium nitrate (UAN), and rainfall timing after application of bispyribac (22.5 g ai ha^{-1}) on control of five-leaf barnyardgrass at 14 d after treatment in the greenhouse. Abbreviations: OSL/NIS, an organosilicone-based nonionic surfactant spray adjuvant that is a proprietary blend of polyalkyleneoxide-modified polydimethylsiloxane and polyoxypropylene–polyoxyethylene copolymers; MSO/OSL, a methylated seed oil/organosilicone–based nonionic emulsifier adjuvant that is a proprietary blend of polyalkyleneoxide-modified polydimethylsiloxane, nonionic emulsifiers, and methyl esters of C16–C18 fatty acids. Bispyribac was applied at 22.5 g ai ha^{-1} in all treatments at a spray volume of 190 L ha^{-1} and 140 kPa pressure. Regression analysis was conducted for each adjuvant type applied with or without UAN across all rainfall timings except 0 and 24 h rainfall timing. Data were fit to sigmoidal models. Model for OSL/NIS without UAN (R^2 = 0.99) is y = 97.1/[1+ $e(x$ − 0.37)/0.32]. Model for OSL/NIS + UAN (R^2 = 0.99) is y = 100.4/[1 + $e(x$ − 0.21)/0.18]. Model for MSO/OSL without UAN (R^2 = 0.99) is y = 85.2/(1 + $e(x$ − 0.44)/0.27). Model for MSO/OSL + UAN (R^2 = 0.96) is y = 98.6/(1 + $e(x$ + 0.27)/0.53). A 32% UAN solution at 2% (v/v) was used in UAN-containing treatments. Rainfall (2.54 cm) was applied with an indoor rainfall simulator. Reduction is expressed as percent fresh weight reduction compared with aboveground portion of nontreated plants (15 g fresh weight at 14 d after application). Fresh weight reduction when averaged across all rainfall timings for OSL/NIS, OSL/NIS + UAN, MSO/OSL, and MSO/OSL + UAN treatments was 80, 90, 69, and 92%, respectively. Fresh weight reduction when averaged across adjuvant treatments for rainfall timings of 0, 0.25, 0.5, 1, 4, 12, and 24 h after bispyribac application was 85, 48, 68, 87, 95, 96, and 97%, respectively. The LSD value (P = 0.05) for adjuvant treatments when averaged across rainfall timings and rainfall timings when averaged across adjuvant treatments was 6 and 7, respectively.

Fresh weight reduction increased sharply for all treatments between rainfall timings of 0.25 to 4 h after bispyribac application regardless of adjuvant type and whether or not UAN was added. In general, a 1- to 2-h period between bispyribac (applied with either adjuvant and with UAN) application and rainfall resulted in a plateau level of control with essentially 100% reduction of fresh weight of barnyardgrass. The exception was applying bispyribac with MSO/OSL without UAN, which provide no better than 87% fresh weight reduction, even when simulated rainfall was applied as late as 24 h after herbicide application (data not shown).

The addition of UAN to bispyribac applied with either adjuvant often decreased the rainfast time period required, to provide similar control levels as to plants not receiving rainfall to 1 h (Figure 1). A 1-h interval between bispyribac applied with OSL/NIS plus UAN and a rainfall event resulted in 100% biomass reduction of barnyardgrass, whereas a 4-h interval was required for 99% reduction with bispyribac applied with MSO/OSL plus UAN. Bispyribac plus OSL/NIS applied without UAN required a 12-h interval between herbicide application and a rainfall event to provide 99% biomass reduction. Applying bispyribac with OSL/NIS and UAN provided the shortest rainfast period and decreased the rainfast period from 8 h (current registered rainfast period) to 1 h after application of bispyribac.

Addition of UAN to either adjuvant applied with bispyribac increased fresh weight reduction of barnyardgrass compared with bispyribac applied with OSL/NIS or MSO/OSL in the absence of UAN when averaged across rainfall timings. Applying bispyribac with either OSL/NIS or MSO/OSL plus UAN provided similar levels of barnyardgrass control, with no difference between nonionic spray adjuvant type when UAN was added. The observation of better barnyardgrass control in the rainfastness experiment when a rainfall event was applied at least 4 h after treatment compared with no rainfall treatment led to conducting the soil moisture content research.

Soil Moisture Content. Interaction between herbicide treatment and soil moisture content data was significant for visual injury (P < 0.001) and biomass reduction (P = 0.0154). Thus, data are presented for each herbicide treatment by soil moisture content combination. Increasing SMC resulted in greater efficacy from bispyribac applied with and without UAN. Injury at 4 DAT ranged from 15% with bispyribac plus OSL/NIS and UAN under dry soil conditions (11% SMC) to 32% with bispyribac plus OSL/NIS and UAN under flooded soil conditions (49% SMC) (Table 3). Biomass reduction ranged from 45 to 99%, with biomass reduction increasing with SMC. The addition of UAN to bispyribac spray solution increased herbicide efficacy compared with no UAN addition to bispyribac under all SMC conditions, except when soil was dry (11% SMC) or extremely wet (49% SMC). The addition of UAN to bispyribac spray solution resulted in greater than 94% biomass reduction when SMC was 29% or greater. Reduced efficacy from bispyribac can be explained by dry soil conditions. Preflood applications of bispyribac are to be made when the soil surface is wet (Anonymous 2006), but dry soil conditions are often needed to apply herbicides and fertilizers by ground equipment. Additionally, increased efficacy from bispyribac applied 1 to 24 h before a rainfall event compared with no rainfall (effect of rainfall timing experiment) could be explained by higher soil moisture.

An 8-h rainfast period is required when bispyribac is applied with a registered spray adjuvant in the absence of UAN (Anonymous 2006). The addition of UAN to bispyribac decreased the rainfast period to 1 or 4 h when OSL/NIS or MSO/OSL were applied with bispyribac, respectively. Adding UAN to bispyribac is a viable option for enhancing bispyribac efficacy and reducing the time period required between bispyribac application and a washoff rainfall event. Applying bispyribac with an approved spray adjuvant and UAN under moist soil conditions (approximately 29 to 49%) should optimize bispyribac efficacy on sensitive weeds. The addition of UAN to bispyribac spray solution improved the flexibility and utility of the herbicide by improving herbicide efficacy, decreasing required rainfast period, and enhancing weed control across a variety of soil moisture conditions. Bispyribac had better weed control performance and a shorter rain-free period when applied with OSL/NIS compared with MSO/OSL.

Table 3. Effects of soil moisture content (SMC) and addition of urea ammonium nitrate (UAN) to bispyribac spray solution on injury and biomass reduction to four-leaf barnyardgrass in the greenhouse 4 and 14 d after treatment (DAT).[a]

		Visual injury 4 DAT				Biomass reduction 14 DAT[e]			
		SMC (%)[f]							
Herbicide treatment[b,c]	UAN rate[d]	11	29	40	49	11	29	40	49
	% (v/v)	%							
Bispyribac + OSL/NIS	0	16	24	21	32	45	82	92	99
Bispyribac + OSL/NIS	2	15	35	33	32	51	95	97	99
LSD (0.05)[c]		3.5				4.5			

[a] Means across columns (soil moisture content) and rows (herbicide treatment) are separated according to LSD value at P = 0.05.
[b] Bispyribac was applied at 22.5 g ai ha^{-1} in all treatments at a spray volume of 190 L ha^{-1} and 140 kPa pressure.
[c] OSL/NIS is an organosilicone-based nonionic adjuvant[2] that is a proprietary blend of polyalkyleneoxide-modified polydimethylsiloxane and polyoxypropylene–polyoxyethylene copolymers.
[d] A 32% urea ammonium nitrate liquid solution was used in treatments.
[e] Reduction is expressed as a percent fresh weight reduction compared with aboveground portion of nontreated plants (16.8 g $plant^{-1}$ at 14 DAT).
[f] Treatments included 11% SMC (dry), 29% SMC (subirrigated for 6 h once every 2 d), 40% SMC (subirrigated continuously for a 4-d period before herbicide application), and 49% SMC (flood irrigated up to soil level for 4 d before herbicide application).

Sources of Materials

[1] Barnyardgrass seed, Azlin Seed Service, P.O. Box 914, Leland, MS 38756.

[2] Kinetic HV®, 99% proprietary blend of polyalkyleneoxide-modified polydimethylsiloxane and polyoxypropylene–polyoxyethylene copolymers, Helena Chemical Company, Suite 300, 225 Schilling Boulevard, Collierville, TN 38017.

[3] 8002E flat fan nozzle, TeeJet, P.O. Box 7900, Wheaton, IL 60189-7900.

[4] DyneAmic®, 99% proprietary blend of polyalkyleneoxide-modified polydimethylsiloxane, nonionic emulsifiers, and methyl esters of C16–C18 fatty acids, Helena Chemical Company, Suite 300, 225 Schilling Boulevard, Collierville, TN 38017.

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